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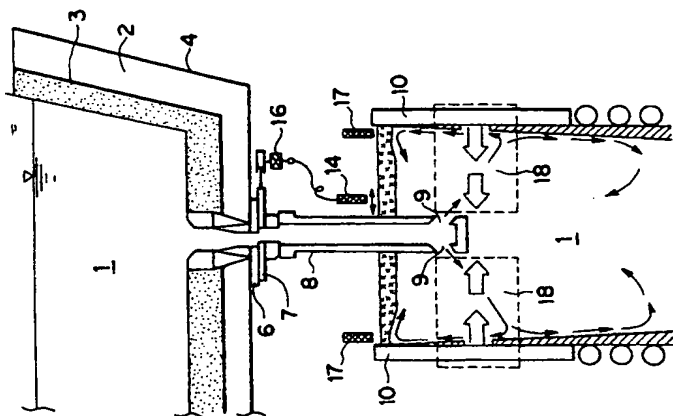
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**AT DE FR GB**(71) Applicant: **NKK CORPORATION**  
**1-2, Marunouchi 1-chome Chiyoda-ku**  
**Tokyo 100(JP)**(72) Inventor: **Kubota, Jun, c/o NKK Corporation**  
**1-1 Minamiwatarida-cho**  
**Kawasaki-ku, Kawasaki 210(JP)**  
Inventor: **Shirayama, Akira, c/o NKK**  
**Corporation**  
**1-1 Minamiwatarida-cho**  
**Kawasaki-ku, Kawasaki 210(JP)**Inventor: **Masaoka, Toshio, c/o NKK**  
**Corporation****1-1 Minamiwatarida-cho**  
**Kawasaki-ku, Kawasaki 210(JP)**Inventor: **Okimoto, Kazutaka, c/o NKK**  
**Corporation****1-1 Minamiwatarida-cho**  
**Kawasaki-ku, Kawasaki 210(JP)**Inventor: **Mori, Takashi, c/o NKK Corporation**  
**1-1 Minamiwatarida-cho**  
**Kawasaki-ku, Kawasaki 210(JP)**(74) Representative: **Füchsle, Klaus, Dipl.-Ing. et al.**  
**Hoffmann . Eitle & Partner Patentanwälte**  
**Arabellastrasse 4**  
**W-8000 München 81 (DE)**(54) **Method for continuous casting of slab.**

(57) A method for continuous casting of a slab, comprises the steps of feeding molten steel into a mold (10) through exit ports (9) of an immersion nozzle (8); controlling a stream of the molten steel by an electromagnetic stirrer (18) having a linearly shifting magnetic field; a first control step of controlling a frequency of wave of the shifting magnetic field to be higher than a frequency having one cycle period of time, during which the stream of the molten steel poured from the immersion nozzle passes through an area, the area which the linearly shifting magnetic field being introduced to; and a second control step of controlling the frequency of the wave of the linearly shifting magnetic field to be lower than a frequency making a density of the magnetic fluxes of the leanerly shifting magnetic field high enough to apply a braking force to the molten steel.

**FIG. 5**

The present invention relates to a method for continuous casting of a slab, and more particularly to a method for continuous casting of a slab wherein wave of molten steel surface is depressed by introducing an electro magnetic force to the molten steel in a mold.

Molten steel is usually poured from a tundish into a mold through an immersion nozzle to prevent the molten steel from being oxidized. The immersion nozzle prevents the molten steel from being exposed to the air. The immersion nozzle for continuous casting of a slab has a pair of exit ports having openings at its lower end. Molten steel is poured into a mold through the exit ports of the immersion nozzle positioned at the center of the mold toward the circumference inside the mold.

It is a subject matter of the recent years in continuous casting of steel to increase a casting speed, namely, a speed of pouring molten steel into a mold for increasing a productivity of a continuous casting machine. However, when the casting speed is increased to more than 1.5 m/ min, molten steel in the mold is violently disturbed. Various waves of the molten steel of from a wavelength of several meters to a short wavelength of several centimeters are generated on the surface of molten steel, making a portion of the immersion nozzle as a fulcrum, whereby the wave height of the molten steel becomes large. Mold powder is entangled in the molten steel by such wave of the molten steel surface. The mold powder entangled in the molten steel and non-metallic inclusions produced at a refining process are prevented by a violent disturbance of the molten steel in the mold from rising up to the surface of the molten steel. As the result, those inclusions are hard to remove from the molten steel in the mold. The inclusions entangled in a slab appear as surface defects and inner defects of a product having passed through a final process. Those surface defects and inner defects of a product greatly lower quality of the product.

As a prior art to prevent such inclusions entangled in a slab, a method for electromagnetically stirring molten steel in a mold, which is disclosed in Japanese Examined Patent Publication No. 10305/89, can be pointed out. In the prior art, an electromagnetic stirrer is placed near meniscus on a wide side of a mold in a continuous casting apparatus. An electromagnetic inducing force is applied to molten steel in a direction of forcing back the molten steel along a direction of a width of the mold from a narrow side of the mold toward the immersion nozzle by use of the electromagnetic stirrer. A flow speed of the molten steel poured into the mold from the immersion nozzle is decreased. Owing to the decrease of the flow speed, the wave motion of the molten steel surface in the mold are decreased and a disturbance of the molten steel therein is depressed.

A magnetic field generator used in the prior art is of a linearly shifting magnetic field type. Therefore, an appropriate value and a frequency of electric current should be determined. The frequency has been determined as follows:

Lorentz force acting on a poured stream of the molten steel should be enhanced to elevate the damping ratio of the flow speed of the poured molten steel. To enhance the Lorentz force, a relative speed of the poured stream of molten steel to a magnetic flux from the narrow side of the mold toward the immersion nozzle should be increased. Accordingly, a shifting speed of the magnetic flux, that is, a frequency of the magnetic flux should be increased. However, when the frequency of the magnetic flux is increased, a magnetic permeability of stainless steel and mold copper plate composing a frame of the mold is lowered and a magnetic permeability of the molten steel is also lowered. Resultantly, the density of the magnetic flux acting effectively on the poured stream of the molten steel from the immersion nozzle is decreased. A frequency of 0.5 Hz as the appropriate frequency satisfying a condition of both Lorentz force and the magnetic permeability has customarily been used.

Figure 1 is a graphical representation showing the magnitude of wave of molten steel surface in a mold, when the value of electric current in a magnetic field generator is varied under the condition of electric current frequency of 0.5 Hz in the magnetic field generator. A direction of shift of a magnetic field is a direction of from the narrow side of the mold toward the immersion nozzle. The magnitude of the wave is represented with an average value of the amplitude of wave of molten steel surface, which are obtained by measuring the amplitude of the wave of molten steel for ten minutes, at positions 40 mm away from the narrow side of the mold and 40 mm away from the wide side of the mold. As shown in Figure 2, the wave motions are substantially composed of a short period wave 30 having a period of about 1 to 2 sec. and a long period wave 31 having a period of about 10 to 15 sec. The amplitude of the wave of molten steel is a wave height difference 32 between two wave heights. One is a wave height showing the maximum height of the short period wave at a moment closest to a moment when the long period wave shows the maximum height and the other is a height of wave showing the minimum height of the short period wave at a moment when the long period wave shows the minimum height. Lines A, B, C and D in Figure 2 were carried out under the following condition.

In line A, a mold had a width of 850 mm. An immersion nozzle had square openings each directed downwardly at 35° relative to a horizontal line. A casting speed of molten steel was 1.6 m/min. In line B, a

mold had a width of 1050 mm. An immersion nozzle had square openings each directed downwardly at 35° relative to a horizontal line. A casting speed of molten steel was 1.8 m/min. In line C, a mold had a width of 1250 mm. An immersion nozzle had square openings each directed downwardly at 45° relative to a horizontal line. A casting speed of molten steel was 2.3 m/min. In line D, a mold had a width of 1350 mm. An immersion nozzle had square openings each directed downwardly at 45° relative to a horizontal line.

A casting speed of molten steel was 2.0 m/min. In any of the cases of the lines A, B, C and D, a frequency in a magnetic field generator was 0.5 Hz.

Under the conditions of A and B that the casting speed of molten steel is comparatively small and the width of the mold is small, as electric current in the magnetic field generator is increased, the effect of depressing the wave of the molten steel surface is getting larger. But, under the conditions of C and D that the casting speed of molten steel is comparatively large and the width of the mold is large, when electric current in the magnetic field generator is excessively increased, the effect of depressing the wave of the molten steel becomes small, which promotes the increase of the wave motions on the contrary.

It is an object of the present invention to provide a method for continuous casting of a slab wherein wave of molten steel in a mold can be depressed under a flexible control condition of operation.

To attain the above-mentioned object, the present invention provides a method for continuous casting of a slab, comprising the steps of:

feeding molten steel into a mold through exit ports of an immersion nozzle, the mold having a pair of wide sides and a pair of narrow sides ;

controlling a stream of the molten steel by use of an electromagnetic stirrer having a linearly shifting magnetic field, a direction of the linearly shifting magnetic field being toward the immersion nozzle positioned at the center of the mold from the pair of the narrow sides and distributions of magnetic fluxes of said linearly shifting magnetic field being symmetrical as regard to a center line of the immersion nozzle ;

a first control step of controlling a frequency of wave of the shifting magnetic field to be higher than a frequency having one cycle period of time, during which a stream of the molten steel poured into the mold from the immersion nozzle passes through an area, to which the linearly shifting magnetic field is introduced and having an upper limit and a lower limit ;

a second control step of controlling the frequency of the wave of the linearly shifting magnetic field to be lower than a frequency making density of the magnetic fluxes of the shifting magnetic field high enough to introduce a braking force to the molten steel, the frequency of the wave being controlled to be a predetermined frequency or more.

The above objects and other objects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the appended drawings.

Figure 1 is a graphical representation showing a magnitude of wave of a molten steel surface adjacent to the narrow side of a mold when a frequency of electric current in a magnetic field generator is 0.5 Hz ;

Figure 2 (A) and (B) are graphical representations explaining a definition of an amplitude of the wave of the molten steel surface;

Figure 3 is a schematic illustration showing a stream of the molten steel poured into the mold from an immersion nozzle of the present invention;

Figure 4 is a graphical representation showing the relationship between frequency of an electric current in the magnetic field generator and an average maximum value of the magnetic fluxes per hour, which is obtained by calculation, of the present invention.

Figure 5 is a vertical sectional view illustrating an apparatus for controlling a molten steel surface used in the method for continuous casting of the present invention;

Figure 6 is a wiring diagram showing a coil of the magnetic field generator seen from the upper side of the mold and used in the present invention;

Figure 7 is a graphical representation showing the results of an operation of continuous casting which depresses wave of the molten steel surface adjacent to the narrow side of the mold, the operation being carried out under the condition of a large width of the mold and a comparatively large casting speed of molten steel in the present invention ;

Figure 8 is a graphical representation showing the results of an operation of continuous casting which depresses wave of the molten steel surface adjacent to the narrow side of the mold, the operation being carried out under the condition of a large width of the mold and a comparatively large casting speed of molten steel in the present invention;

Figure 9 is a graphical representation showing the results of an operation of continuous casting which depresses wave of the molten steel surface adjacent to the narrow side of the mold, the operation being carried out under the condition of a large width of the mold and a comparatively large casting speed of molten steel in the present invention;

Figure 10 is a graphical representation showing the results of an operation of continuous casting which depresses wave the molten steel surface adjacent to the narrow side of the mold, the operation being carried out under the condition of a large width of the mold and a comparatively large casting speed of molten steel in the present invention;

Figure 11 is a graphical representation showing the results of Figures 7 to 10, the frequency of electric current being represented by the the abscissa and the wave adjacent to the narrow side of the mold by the ordinate;

Figure 12 is a graphical representation showing a change of the effect of depressing the wave of the molten steel surface adjacent to the narrow side of the mold when the value of electric current in the magnetic field generator is varied in the present invention;

Figure 13 is a graphical representation representing the lower limit of a frequency of electric current for depressing the wave of the molten steel surface with an effective braking parameter and an angle of the axis of the exit port of the immersion nozzle in the direction of poured molten steel; and

Figure 14 is a graphical representation showing a straight line indicating a lower limit of a frequency of electric current for depressing the wave of the molten steel surface and a straight line indicating a frequency of electric current obtained by multiplying the above frequency by integer.

The magnetic field generator of the present invention is of a linearly shifting magnetic field type. A magnetic flux shifts from the narrow side of a mold toward an immersion nozzle in the direction of crossing at right angles a direction of withdrawing a slab. Or the magnetic flux shifts from the narrow side of the mold to toward the imersion nozzle making a certain angle to the direction of crossing at right angles the direction of the withdrawal of the slab. That is to say, the magnetic flux forwads an adverse direction against the stream of the molten steel poured from the immersion nozzle. Accordingly, a density of the magnetic flux at a certain point inside the mold varies periodically. Therefore, the stream of the molten steel poured from the immersion nozzle does not always cross a magnetic flux having a constant density in terms of time. There occurs a difference in the total amount of electromagnetic forces received by the stream of the molten steel until the molten steel has passed through an area, to which the linearly shifting magnetic field is introduced, depending on a difference in moments when the molten steel is poured from the immersion nozzle.

The present inventors have found the following:

Firstly, a period of time, which is necessary for a certain fragment of the stream of the molten steel poured from the immersion nozzle to pass through an area, to which the linearly shifting magnetic field is introduced, is determined by a width of the mold, an amount of the molten steel poured from the immersion nozzle, an angle of discharge of molten steel from the immersion nozzle, a depth of exit ports of the immersion nozzle immersed into the molten steel and a frequency of electric current in the magnetic field generator. The amount of the molten steel is determined by the width of the mold and a casting speed.

Secondly, times of crossings of magnetic fluxes with stream of molten steel while the stream of the molten steel poured from the mold are passing through an area, to which a linearly shifting magnetic field is introduced, are determined by a width of a mold, an average amount of molten steel poured from the immersion nozzle which is determined by the width of the mold and a casting speed, an angle of the molten steel poured from the immersion nozzle, a depth of exit ports of the immersion nozzle immersed into the molten steel and a frequency of electric current in the magnetic field generator.

Thirdly, it is determined depending on how many times the molten steel poured from the immersion nozzle cross the magnetic fluxes while the molten steel are passing through the area, to which the linearly shifting magnetic field is introduced, how large a degree of a phenomenon is. The phenomenon is that there occurs a difference in the total amounts of magnitudes of electromagnetic forces the stream of the molten steel receive by difference of a time interval required for the molten steel to be poured from the immersion nozzle until it has passed through the area, to which the linearly shifting magnetic field is introduced.

In order to decrease the phenomenon, it can be considered that the molten steel poured from the immersion nozzle crosses the shifting magnetic field, necessarily with the same times of the crossing, while it passes through the area, to which the linearly shifting field is introduced. Two methods are conceivable therefor.

A first method is a method wherein molten steel poured from the immersion nozzle passes, by taking the passing time as long as possible, through the area, to which the linearly shifting magnetic field is introduced. A speed of the stream of the molten steel poured from the immersion nozzle is decreased by decreasing a casting speed. Or the stream of the molten steel poured from the immersion nozzle is caused to flow in parallel with the direction of shift of the magnetic flux in the area, to which the linearly shifting magnetic field is introduced, by making smaller an angle of the molten steel poured from the immersion nozzle with regard to the horizontal line. However, when the casting speed is decreased, a production

efficiency of a continuous casting machine is lowered. When the angle of the molten steel poured from the immersion nozzle is decreased, the entanglement of mold powder in the stream of the molten steel can be generated, which gives rise to the entanglement of inclusions in a slab. Therefore, this first method is not advantageous.

A second method is found by the present inventors who have conducted a test by use of a continuous casting machine. The frequency of electric current of the magnetic field generator is selected and a shifting speed of magnetic fluxes of the linearly shifting magnetic field is controlled. The frequency of electric current is set at a necessary minimum frequency or more so that any of the fragments of the stream of the molten steel can cross the moving magnetic flux at least once while the fragment of the molten steel poured from the immersion nozzle is passing through the area, to which the linearly shifting magnetic field is introduced. That is to say, since any of the fragments of molten steel poured from the immersion nozzle undergoes at least once a braking force of the density of the magnetic flux of one cycle of the linearly shifting magnetic field during its passing through the area, to which the linearly shifting magnetic field is introduced, there occurs no unevenness of degree of the introduction of the magnetic field to the molten steel, i.e. the unbalance that some parts of the molten steel are braked and others are not is not braked. If the selected frequency is a necessary minimum frequency or a frequency which is made by multiplying the minimum frequency in integer, any of the fragments of molten steel undergoes the braking force equally, the wave of the molten steel surface in the mold is further decreased.

According to this second method, since there is no direct influence on the casting speed and the angle of the molten steel poured from the immersion nozzle, the wave of the molten steel on surface can be decreased. However, when the frequency of electric current in the magnetic field generator is increased, the magnetic permeability is lowered, which lowers the density of the magnetic flux acting effectively on the stream of the molten steel poured from the immersion nozzle. Accordingly, this frequency is desired to be the minimum necessary frequency found by using the method described below or the frequency produced by multiplying the minimum frequency in integer. For example, the frequency multiplied by integer becomes a frequency multiplied by two or three. Since the braking force, with which the shifting magnetic field acts on the fragments of the molten steel poured from the immersion nozzle, increases in proportion to the product of the square of the magnetic flux and the frequency, it is effective to select a frequency multiplied by integer which makes the product maximum.

The minimum frequency of electric current necessary in the second method is found as follows:

An interval of time  $P$  [ sec ], at which the magnetic flux shifting in the area, to which linearly shifting magnetic field is applied, passes periodically in the magnetic field generator, is represented with the formula (1):

$$P = 1 / ( N \cdot F ) \quad (1)$$

where  $N$  is a number of poles in the magnetic field generator and  $F$  is a frequency of electric current in the magnetic field generator [ Hz ]

Figure 3 is a schematic illustration showing a stream of molten steel poured from the immersion nozzle of the present invention. As shown in Figure 3, the molten steel poured from the exit ports 29 of the immersion nozzle enter the area, to which the linearly shifting magnetic field is introduced, reaches the lower end 34 of the area and goes out of the area. The period of time of from the entry of the molten steel into the area to the going-out of the molten steel from the area, that is, an effective braking period of time  $T$  [sec.] is represented with the formula (2).

$$T = ( W - D ) / ( V \cdot \sin \theta ) \quad (2)$$

where

$V$  is an average speed of the stream of the molten steel [m/sec.], at which the stream of the molten steel poured from the immersion nozzle passes through the area. The area, to which the linearly shifting magnetic field is introduced, is an area which has a density of the magnetic flux of 1/2 of the maximum value as an average value of the magnetic flux per hour, which is measured at the center of the mold in the direction of the thickness of the mold;

$\theta$  is an angle [rad] formed by the stream of the molten steel poured from the exit ports of the immersion nozzle relative to the horizontal line when the stream of the molten steel passes through the area, to which the linearly shifting magnetic field is introduced;

$W$  is a width [m] of the area, to which the linearly shifting magnetic field is introduced, in the direction of the height of the mold;

D is a distance[m] of from the upper end of the exit port of the immersion nozzle to the upper end of the area, to which the linearly shifting magnetic field is introduced, when the end of the exit port of the immersion nozzle is located in the area, to which the linearly shifting magnetic field is introduced and D is equal to 0 [m] when the end of the exit port of the immersion nozzle is out of the introduced area.

On the other hand, when a downwardly directed angle  $\alpha$  of the exit port of the immersion nozzle is small or an angle formed by the direction of the stream of the molten steel poured from the immersion nozzle and the direction of the shifting of the magnetic flux is small, the stream reaches a solid shell adjacent to the narrow sides of the mold before the stream of the molten steel goes out of the upper limit or the lower limit of the linearly shifting magnetic field. Time which the stream of the molten steel takes for the going-out of the exit port of the immersion nozzle to the arrival at the solid shell adjacent to the narrow side of the mold is a effective braking time T[sec.]. The time is represented by the following formula(3):

$$T = A / ( 2 \cdot V \cos \theta ) \quad (3)$$

where A is a width of cast slab.

It is very difficult to actually measure the values of V and  $\theta$  in an operation of an continuous casting machine. Therefore, the present inventors reproduced an actual casting by using water model and measured V and  $\theta$ . However, a braking effect by the magnetic field generator was not added to the V and  $\theta$

From the formulae (1) (2) and (3), the minimum frequency necessary in order that total amount of magnetic fluxes, which any of the fragments of molten steel poured from the immersion nozzle crosses during its passing through the area, to which the linearly shifting magnetic field is introduced, can be the same, is represented as follows, by making  $P = T$ .

The minimum frequency of electric current is represented by the following formula (4) in case that the stream of the molten steel poured from immersion nozzle goes out of the lower limit of the linearly shifting magnetic field :

$$F = ( V \cdot \sin \theta ) / \{ N \cdot ( W - D ) \} \quad (4)$$

The minimum frequency of electric current is represented by the following formula (5) in case that the stream of the molten steel poured from immersion nozzle is in the range of between the lower limit of the linearly shifting magnetic field :

$$F = ( 2 \cdot V \cdot \cos \theta ) / ( N \cdot A ) \quad (5)$$

In Figure 3, symbols in the formula (4) and (5) are explained. Molten steel is poured into a mold from exit ports 29 of immersion nozzle 8. The molten steel poured from the exit ports of the immersion nozzle 8 passes through an area, to which a linearly shifting magnetic field is introduced, at an average flow speed 27 (V) at an angle 26 of ( $\theta$ ) to the horizontal line. Reference numeral 24 denotes a width of a magnetic field generator in the direction of a height of a coil.

A width 23 (W) of the linearly shifting magnetic field in the direction of a height of the mold in the area, to which the linearly shifting magnetic field is introduced is in between the upper end 33 and the lower end 34 of the introduced area. In the case that the upper end of the exit port of the immersion nozzle is located in the area, to which the linearly shifting magnetic field is introduced, the shifting magnetic field does not act effectively on the stream of the molten steel in the area of a distance 25 (D) of from the upper end of the exit port of the immersion nozzle to the lower end 34 of the area, to which the linearly shifting magnetic field is introduced. The molten steel poured into the mold having the upper end 20 and the lower end 22 has a molten steel surface 21.

Figure 4 is a graphical representation showing the relationship between the frequency of electric current in the magnetic field generator and the maximum value of average magnetic fluxes per hour in the mold, which was measured in a continuous casting machine. When the frequency of electric current is increased, a magnetic permeability of stainless steel plate and copper plate composing a frame of the mold is lowered, which lowers the densities of the magnetic fluxes. The densities of the magnetic fluxes in a mold of each continuous casting machines are not always equal to those in Figure 4 because of differences of structures and performances of individual apparatuses. According to the test conducted by the present inventors, in order to effectively brake a flow speed of the molten steel poured from an immersion nozzle, it is desirable that densities of magnetic fluxes in the mold are at least 1200 gauss. In the case of Figure 4, a frequency of electric current of 2.8 Hz or less is selected, and the shifting speed of the linearly shifting magnetic field is

controlled.

However, since the values of the average flow speed of the molten steel and the angle  $\theta$  cannot be measured in an actual operation of a continuous casting, there is inconvenience such that a necessary minimum frequency or a frequency which is calculated by multiplying the minimum frequency by integer are not immediately obtained. The present inventors have found a way of solving the inconvenience.

The results of the test conducted by the mentioned water model was compared with those conducted by a continuous casting machine, using an effective braking parameter E. The effective braking parameter E is represented with a width A[m] of a mold for continuous casting, a thickness B[m] of casting, a casting speed C[m/sec.] and an effective area S[m<sup>2</sup>] of the exit port of the immersion nozzle.

The test by the continuous casting was carried out on the conditions as follows :

a width of a slab cast : 0.7 to 2.6 m ; thickness of a slab cast : 0.1 to 0.3 m ; casting speed : 0.6 to 5.0 m/min. ; an angle of poured molten steel from an immersion nozzle ; ranging 60° directed downwardly to 15° directed upwardly ; and capacity of continuous casting machine per strand ; 15 ton /min.

The water model test was carried out corresponding to the conditions of the above test by the continuous casting.

Using the effective braking parameter E and the angle  $\alpha$  of the molten steel poured from the exit port of the immersion nozzle, the minimum frequency F of electric current necessary for controlling the wave of the molten steel in the mold is represented as seen in Fig. 13. In Fig. 13,  $\alpha$  is an angle formed by an axis of the exit port of the immersion nozzle and the horizontal line. Frequency calculated by multiplying the minimum frequency in integer is represented as in Fig. 14.

An effective braking parameter E is represented in response to the angle  $\alpha$  formed by an axis of the exit port of the immersion nozzle and the horizontal line. The parameter E is represented by the following formula (6) in case that the angle  $\alpha$  is within the range of 60° to 25° both directed downwardly :

$$E = (A \cdot B \cdot C) / \{ N \cdot (W - D) \cdot S \} \quad (6)$$

The parameter E is represented by the following formula (7) in case that the angle  $\alpha$  is within the range of over 25° directed downwardly and below 15° directed upwardly :

$$E = 4 \cdot B \cdot C (\cos \alpha)^2 / \{ N \cdot A \cdot S \} \quad (7)$$

The formulas (6) and (7) are represented with a width A[m] of a mold for continuous casting, a thickness B[m] of casting, a casting speed C[m/sec.] and an effective area S[m<sup>2</sup>] of the exit port of the immersion nozzle. The area S [m<sup>2</sup>] is a section area crossing perpendicularly the axis of the exit port of the immersion nozzle and the shape of the section area can be such as a circle, an ellipse, a square, a rectangle and an egg-shape.

In Fig. 13, each of the straight lines are drawn in response to the respective angles  $\alpha$  of the exit port. Straight line(a) shows a case of the angle  $\alpha$  being in the range of from 60° to 35° both directed downwardly, straight line(b) a case of the angle  $\alpha$  being in the range of over 35° to 25° both directed downwardly, and straight line(c) a case of the angle  $\alpha$  being in the range of over 25° directed downwardly and 15° inclusive, directed upwardly. The straight line(a) connects points ( E = 0, F = 0 ) and ( E = 5, F = 1.5 ), the straight line(b) points ( E = 0, F = 0 ) and ( E = 5, F = 1.4 ) and the straight line(c) points ( E = 0, F = 0 ) and ( E = 5, F = 1.3 ).

#### Example

An example of the present invention will now be described with specific reference to the appended drawings.

Fig.5 is a vertical sectional view illustrating a molten steel surface controller used in the method for continuous casting of steel of the present invention. A tundish 2 is mounted above a mold 10 for continuous casting, and molten steel is fed from a ladle ( not shown ) to the tundish 2. A inside wall of the tundish is lined with refractory 3, and an outside of the tundish is covered with a steel shell 4. A sliding nozzle 5 is placed at a bottom of the tundish 2. The sliding nozzle 5 has an immovable plate 6 fixed to the steel shell 4 and a sliding plate 7 sliding relative to the immovable plate 6. The nozzle 5 is opened and closed by sliding the sliding plate 7.

An immersion nozzle 8 is fixed to the lower side face of the sliding plate 7. A lower end portion of the immersion nozzle 8 is immersed in a molten steel 1 already poured into the mold 10. The molten steel 1 is poured into the mold 10 through a pair of exit ports 9 placed symmetrically on both left and right sides. A

molten steel surface sensor 14 is arranged facing to the surface of molten steel in the mold to detect positions of the molten steel surface and change of the positions of the molten steel surface. The molten steel surface sensor 14 is connected to an input side of a monitor in a control device 16 for controlling a sliding nozzle opening angle. Independently from the molten steel surface sensor 14, two molten steel surface sensors 17 are positioned on the narrow sides of the mold, each of the sensors being on each of the both narrow sides of the mold. This molten steel surface sensor 17 is not connected to the control device 16. The molten steel surface sensor 17 monitors the effect of depressing the movement of the wave of the molten steel surface generated by the magnetic field generator of the present invention. The magnetic field generator 18 is placed behind copper plates of both wide sides of the mold.

Table 1 shows a composition of steel provided for the casting of the Examples of the present invention.

Table 2 shows operation conditions of the casting of the Examples of the present invention.

Table 3 shows a specification of the magnetic field generator used in the casting of the Example of the present invention.

Table 1

| Composition   | C          | Si           | Mn         | S             | P            | Soluble A t  |
|---------------|------------|--------------|------------|---------------|--------------|--------------|
| Range ( wt.%) | 0.03 ~0.08 | 0.04 or less | 0.10 ~0.25 | 0.025 or less | 0.25 or less | 0.030 ~0.070 |

Table 2

|  |   |
|--|---|
| Width of Mold                                    | 1550 mm ; 950mm   |
| Thickness of Cast Slab                           | 230 mm  |
| Casting Speed                                    | 2.0 m/min. ; 1.6 m/min.   |
| Flow Rate of Ar gas Blown into Immersion Nozzle  | 10.0 N l /min   |
| Immersion Nozzle                                 | Inside Diameter : 90 mm ; Exit Port : Square-Shaped ; and Angle of Exit Port : 45 ° directed downwardly |
| Temperature of Molten Steel in Tundish           | 1545 ~ 1565 ° C   |
| Immersion Depth of Exit Port of Immersion Nozzle | 270 mm above Molten Steel Surface ( Position of Upper End Limit of Immersion Nozzle )                   |

Table 3

|                                    |  |
|------------------------------------|--|
| Magnetic Field                     | Linearly Shifting Magnetic Field                   |
| Capacity                           | 2000KVA/strand ( Three-phase Alternating Current ) |
| Voltage                            | Max. 430 V/strand                                  |
| Electric Current                   | Max. 2700 A/strand                                 |
| Frequency of Electric Current      | 0 ~ 2.6 Hz   |
| Number of Poles                    | 2  |
| Maximum Density of Magnetic Flux B | 0.2 Tesla  |
| W                                  | 0.48 m   |

The maximum density B of the magnetic flux shown in Table 3 is an average density of magnetic flux per hour at a point where an average density of magnetic flux per hour, which is measured at the center of the mold in the direction of the thickness thereof, shows the maximum value. W in Table 3 is a width of an area in the direction of the height of the mold, which has a an average density of magnetic flux per hour of



1/2 of the maximum value of the density of magnetic flux with a position as the center, which shows the maximum value of the average density of magnetic flux per hour, which is measured at the center of the mold in the direction of the thickness thereof.

Figure 6 is a wiring diagram showing a coil in the magnetic field generator used in the present invention.

#### Example-1

Continuous casting of a slab was carried out by controlling the surface of molten steel in the mold by the magnetic field generator as shown in Table 3. The casting conditions are as shown in Table 2.

Firstly, an average flow  $V$  of the molten steel and an angle  $\theta$  under the casting conditions as shown in Table 2 were measured in a water model test wherein a model of a mold scaled down to 1/3 of an actual mold was used. Measured values were converted in calculation to those of a scale of an actual apparatus operation. The values of  $V = 1.15$  m/sec and  $\theta = 0.70$  were obtained. A period of time [ sec ] necessary for a minute stream of the molten steel poured from the immersion nozzle to enter an area, to which a linearly shifting magnetic field is introduced, and go out of the introduced area is calculated by substituting the said values of  $V$  and  $\theta$  for the formula(3), and the time  $T = 0.56$ (sec.) is obtained.

Accordingly, to depress well the wave of the molten steel surface on condition that a casting speed is comparatively large and a width of a mold is large, a time period  $P$ [sec.], for which the magnetic fluxes pass periodically through the area, to which a linearly shifting magnetic field is introduced, is determined at 0.56 sec. or less. A frequency  $F$  of electric current in the magnetic field generator when the time period  $P$ [sec.], is determined to be 0.56 sec. or less is calculated by the formula(3) to be 0.89 (Hz) or more.

By using the above-mentioned results an operation of continuous casting on condition that the casting speed was comparative large and the width of the mold was large was carried out by depressing the wave of the molten steel surface.. The results of the operation are shown in Figures 7.

The abscissa in Figure 7 represents time. The time lapses from the right to the left on the graph. The ordinate represents height of the molten steel surface adjacent to the narrow side of the mold which is measured by the molten steel surface sensor 17. The operation conditions for the results in Figure 7 is listed in Table 2. Figure 7 shows the behavior of Comparison in the case where the magnetic field generator was not used. Since the magnetic field generator was not used, the surface molten steel adjacent to the narrow side of the mold was greatly fluctuated. To depress this fluctuation of the surface molten steel, the magnetic field generator is driven.

Figure 8 shows Comparison wherein the magnetic field generator was driven with the frequency of electric current of 0.5 Hz and with the value of electric current of 1080 A. The frequency of electric current of 0.5 Hz is lower than the lower limit of the frequency of electric current of 0.89 Hz. The value of 0.89 well depresses the wave of the molten steel surface in the mold on condition that the casting speed is comparatively large and the width of the mold is large. That is, the necessary condition for the lower limit of the frequency of electric current under the operation condition as shown in Table 2 is not satisfied. Actually, as shown in Figure 8, there is substantially no effect of depressing the wave of the molten steel surface adjacent to the narrow side of the mold. On the contrary, the wave of the molten steel surface is accelerated.

Figure 9 shows an Example wherein the magnetic field generator is driven with the frequency of electric current of 1.0 Hz and with the value of 1080 A. The frequency of electric current of 1.0 Hz is higher than the lower limit of the frequency of electric current of 0.89 Hz, which well depresses the wave of the molten steel surface on condition that the casting speed is comparatively large and the width of the mold is large. That is, the necessary condition for the lower limit of the frequency of electric current under the operation condition as shown in Table 2 is satisfied. It is well understood that the effect of depressing the wave of the molten steel surface adjacent to the narrow side of the mold is actually great as shown in Figure 9.

Figure 10 shows an Example wherein the magnetic field generator was driven with the frequency of electric current of 2.0 Hz and with the value of electric current of 1080 A. The frequency of electric current of 2.0 Hz is higher than the lower limit of the frequency of electric current of 0.89 Hz, which well depresses the wave of the molten steel surface on condition that the casting speed is comparatively large and the width of the mold is large. That is, the necessary condition for the lower limit of the frequency of electric current under the operation condition as shown in Table 2 is satisfied. It is also well understood that the effect of depressing the wave of the molten steel surface adjacent to the narrow side of the mold is actually great as shown in Figure 10.

Figure 11 shows the relationship of the wave of the molten steel surface adjacent to the narrow side of the mold to the frequency of electric current, which is obtained by summing up the results as shown in

Figures 7 to 10. The abscissa represents the frequency of electric current and the ordinate the wave of the molten steel surface. The wave of the molten steel surface is sufficiently depressed by use of a frequency higher than the lower limit of the frequency of electric current of 0.89 Hz for well depressing the wave of the molten steel surface.

#### Example-2

Figure 12 shows the relationship between the value of electric current in the magnetic field generator and the magnitude of the wave of the molten steel surface adjacent to the narrow side of the mold. The casting conditions are those shown in Table 2. Lines A, B, C and D in Figure 12 were carried out under the following conditions:

For lines A and B, a width of a mold was 950 mm. An immersion nozzle had square openings directed downwardly at  $45^\circ$  to the horizontal line. A casting speed was 1.6 m/min. In line A, a frequency of electric current was 0.5 Hz. In line B, a frequency of electric current was 1.0 Hz. In lines C and D, a width of a mold was 1550 mm. An immersion nozzle had square openings directed downwardly at  $45^\circ$  to the horizontal line. A casting speed was 2.0 m/min. In line C, a frequency of electric current was 0.5 Hz. In line D, a frequency of electric current was 1.0 Hz.

In Figure 12, line A and B show the case that a casting speed was comparatively small and a width of a mold was small.

When the frequencies of electric current were 0.5 Hz and 1.0 Hz, the effect of depressing the wave of the molten steel surface adjacent to the narrow side of the mold was obtained in correspondence with each of the values of electric current.  $V$  was 0.67 m/sec,  $\theta$  was 0.43 rad. and  $W$  was 0.48 under the casting conditions of A and B. The lower limit of the frequency of electric current found by the formula(3) was 0.43 Hz. Since the magnetic field was generated by the lower limit of the frequency of electric current of 0.43 Hz or more, the effect of depressing the wave of the molten steel surface was sufficiently produced. An effective braking parameter  $E$  was 1.2.

In Figure 12, lines C and D show the case that the casting speed is comparatively large and the width of the mold is large.

Under the casting conditions of the lines C and D,  $V$  is 1.15 m/sec,  $\theta$  0.66 rad. and  $W$  0.48 m. The lower limit of the frequency of electric current is 0.89 Hz. The effective braking parameter is 2.6. The case of the line C is the case that the frequency of electric current is 0.5 Hz which is lower than the lower limit of the frequency of electric current  $F$  of 0.89. In this case, when the value of electric current was increased, the wave of the molten steel surface is accelerated.

The case of the line D is a case that the frequency of electric current is 1.0 Hz which is higher than the lower limit of the frequency of electric current  $F$  of 0.89. The effect of depressing the wave of the molten steel surface is obtained in correspondence with each of the values of electric current.

A lower limit of a frequency of electric current for depressing wave of the molten steel surface in the mold is shown in Figure 13. In the case of Figure 13, casting conditions such as a width of casting, a thickness of slab cast, a casting speed, sorts of immersion nozzles and the like are varied in a wide range. A frequency of electric current is represented with the ordinate. A casting condition is represented with an effective braking parameter  $E$  of the abscissa and an angle  $\alpha$  formed by an axis of an exit port of an immersion nozzle in the direction of the molten steel poured and the horizontal line.

In case that the stream of the molten steel poured from the exit port of the immersion nozzle goes out of the lower limit of the linearly shifting magnetic field, i.e., the angle  $\alpha$  is in the range of  $60^\circ$  to  $25^\circ$  both directed downwardly, the effective braking parameter  $E$  is represented by the formular of  $E = (A \cdot B \cdot C) / \{ N \cdot (W - D) \cdot S \}$ . In case that the stream of the molten steel poured from the exit port of the immersion nozzle is in the range of the upper limit and the lower limit of the linearly shifting magnetic field, i.e., the angle  $\alpha$  is in the range of over  $25^\circ$  directed downwardly and below  $15^\circ$  inclusive, directed upwardly, the effective braking parameter  $E$  is represented by the formular of  $E = 4 \cdot B \cdot C (\cos \alpha)^2 / \{ N \cdot A \cdot S \}$ . In Figure 13, the straight line(a) represents a case that the angle  $\alpha$  is in the range of from  $60^\circ$  to  $35^\circ$  both directed downwardly, the straight line(b) a case that the angle  $\alpha$  is in the range of over  $35^\circ$  to  $25^\circ$  both directed downwardly and a case that the angle  $\alpha$  is in the range of over  $25^\circ$  directed downwardly and below  $15^\circ$  inclusive, directed upwardly.

A case that the effective braking parameter  $E$  has a comparative small value of from 1 to 2 represents a case that a width of a mold is comparatively small or a casting speed is small. In the case where  $E$  has a value of from 1 to 2, the lower limit of a frequency of electric current which depresses the wave of the molten steel surface is 0.8 Hz or less. The value of the effective braking parameter is increased as the width of the mold is getting larger or the casting speed is getting more rapid. The lower limit of the frequency of

electric current for depressing the wave of the molten steel surface shows a straight line rising right-wardly with the increase of the value of the effective braking parameter. However, the upper limit of the frequency of electric current allowing the magnetic permeability to lower is constant irrespective of the width of the mold and the casting speed.

5 An example of the casting as shown in Figure 12 is written in Figure 13. Symbols ●, ■, ○ and □ correspond to those of ●, ■, ○ and □ shown in Figure 12. Symbol ○ of Figure 12 represents a case that a width of casting is 1550 mm, a casting speed 2.0 m/min and the angle of the axis of an exit port of an immersion nozzle relative to the horizontal line 45° directed downwardly, but a point of symbol ○ in Figure 13 is located below an straight line of the lower limit of the frequency of electric current shown by the  
10 angle  $\alpha$  of 45°. In line C represented with symbol ○ in Figure 12, the wave of the molten steel surface is accelerated when the value of electric current is increased. This is considered to be because there have been produced some portion of the stream of the molten steel poured from the immersion nozzle which have undergone an electromagnetic braking force and other portion thereof which have not. The wave of the molten steel surface have been increased. Symbol ■ represents a case that the width of casting is 950 mm,  
15 the casting speed 1.6 m/min, the angle of the axis of an exit port of an immersion nozzle relative to the horizontal line 45° directed downward and the lower limit of the frequency of electric current 0.43 Hz. Used frequency of electric current was 1.0 Hz, which is substantially two times larger than the lower limit of the frequency of electric current. Since the magnetic field is generated with the frequency of electric current of the lower limit of the frequency of electric current of 0.43 or larger, the effect of braking the wave of the  
20 molten steel surface is sufficiently produced.

A case is represented in Figure 13, the case being that the stream of the molten steel poured from the exit port of the immersion nozzle has not yet gone out of the range of the upper limit and the lower limit, i.e. the angle  $\alpha$  of the exit port of the immersion nozzle is in the range of over 25° directed downwardly and below 15° inclusive, directed upwardly. Symbol ⊙ shown in Figure 13 is a case that the width of casting is  
25 2100 mm, the thickness of a slab cast 250mm, the casting speed 2.0 m / min. and the angle  $\alpha$  of the exit port of the immersion nozzle 15° directed downward. The effective braking parameter E is 1.1, the frequency of electric current of lower limit 0.40 Hz. Even the frequency of electric current being the standard level of the lower limit of 0.40 Hz is effective in depressing the wave of the molten steel surface. Since this is in the range where the product of the square of the magnetic flux and the frequency of  
30 electric current is expected to be increased even if the frequency of the electric current is further increased, the casting has been carried out by the frequency of 1.2 which is 3 times as large as the frequency of electric current of the lower limit. By this 1.2 Hz, the wave of the molten steel surface has been more effectively depressed. Symbol Δ shown in Figure 13 is a case that the width of casting is 700 mm, the thickness of a slab cast 250mm, the casting speed 3.0 m / min. and 1.5 m / min., and the angle  $\alpha$  the exit  
35 port of the immersion nozzle 5° directed downward. The effective braking parameter E is 5.0 and 2.5, the frequency of electric current of lower limit 1.30 Hz and 0.65 Hz. In case of the casting speed being 3.0 m / min. the frequency of electric current is doubled to be 2.60 Hz and in case of the casting speed being 1.5 m / min. the frequency of electric current is doubled to be 1.30 Hz. In the both cases, the wave of the molten steel surface is well depressed.

40 In Figure 14, a straight line showing the lower limit of the frequency of electric current and a straight line showing the frequency of electric current obtained by multiplying the lower limit of the frequency of electric current by integer are represented when the angle  $\alpha$  of the exit port of the immersion nozzle is in the range of 60° to 25° both directed downwardly.  $r = 1$  is for the standard frequency of electric current of the lower limit,  $r = 2$  is for the two times of the standard frequency and  $r = 3$  is for the three times of the  
45 standard frequency.

In the case of symbol ■, a frequency substantially two times larger than the lower limit of the frequency of electric current is used. Since the stream of the molten steel poured from the immersion nozzle undergoes an electromagnetic braking force twice during its passing through the area, to which the linearly shifting magnetic field is introduced, the wave of the molten steel surface is depressed to such an extent as  
50 satisfied. In this way, the selection of frequencies is not limited to the lower limit of the frequency of electric current. The lower limit of the frequency of electric current or more, or frequency two times or three times larger than the lower limit of the frequency of electric current can be used. However, unless the frequency of electric current is below the upper limit of the frequency of electric current allowing the permeability to lower, the effect of depressing the wave of the molten steel surface cannot be produced.

55 As described above, the wave of the molten steel surface in the mold can be well depressed by driving the magnetic field generator within the range of the frequencies of electric current in the present invention even on the condition that the casting speed is comparatively large and the width of the mold is large. In consequence, the entanglement of mold powder in the molten steel due to the wave of the molten steel

surface is prevented. Moreover, since a violent disturbance of the molten steel, which is generated together with the wave of the molten steel surface is prevented, mold powder entangled in molten steel and non-metallic inclusions in molten steel, which are generated in a process of refining, are not prevented from rising to the surface of molten steel in the mold, which facilitates the removal of those inclusions from the molten steel in the mold.

## Claims

1. A method for continuous casting of a slab, comprising the steps of:
  - feeding molten steel into a mold (10) through exit ports (9) of an immersion nozzle (8), the mold having a pair of wide sides and a pair of narrow sides ; and
  - controlling a stream of the molten steel by use of an electromagnetic stirrer (18) having a linearly shifting magnetic field, a direction of the linearly shifting magnetic field being toward the immersion nozzle positioned at the center of the mold from the pair of the narrow sides and distributions of magnetic fluxes of the linearly shifting magnetic field being symmetrical relative to a center line of the immersion nozzle ;
  - characterized by comprising :
    - a first control step of controlling a frequency of wave of the linearly shifting magnetic field to be higher than a frequency having one cycle period of time, during which the stream of the molten steel poured into the mold from the immersion nozzle passes through an area, the area which the linearly shifting magnetic field being introduced to and having an upper limit and a lower limit ; and
    - a second control step of controlling the frequency of wave of the linearly shifting magnetic field to be lower than a frequency making a density of the magnetic fluxes of the linearly shifting magnetic field high enough to apply a braking force to the molten steel, the frequency of wave being controlled to be a predetermined frequency or less.

2. The method of claim 1, characterized in that said first control step comprises controlling a frequency of electric current for generating the linearly shifting magnetic field to be a value of frequency of electric current or more when the stream of the molten steel poured from the immersion nozzle goes out of the lower limit, the value of frequency being determined by the following formula:

$$F = ( V \cdot \sin \theta ) / \{ N \cdot ( W - D ) \}$$

where

F represents the value of frequency [ Hz ] of the electric current for generating the linearly shifting magnetic field;

V represents average stream speed [ m/sec. ] of the molten steel poured from the immersion nozzle when the stream of the molten steel passes through the introduced area ;

$\theta$  represents an angle[rad] formed by the stream of the molten steel relative to the horizontal line when the stream of the molten steel passes through the introduced area ;

W represents a width[m] of the introduced area in a direction of a height of the mold ;

D represents distance [ m ] of from an upper end of the exit port of the immersion nozzle to an upper limit of the introduced area, when the upper end of the exit port of the immersion nozzle is located in the introduced area ; and

N represents a number of poles in the magnetic field generator.

3. The method of claim 1, characterized in that said first control step includes controlling a frequency of electric current for generating the linearly shifting magnetic field to be a value of frequency of electric current or more, when the stream of the molten steel poured from the immersion nozzle is in a range of between the upper limit and the lower limit, the value of frequency being determined by the following formula :

$$F = ( 2 \cdot V \cdot \cos \theta ) / ( N \cdot A )$$

where

F represents the value of frequency[Hz] of electric current for generating the linearly shifting magnetic field;

V represents average stream speed [m/sec.] of the molten steel poured from the immersion nozzle

when the stream of the molten steel passes through the introduced area ;

$\theta$  represents an angle[rad] formed by the stream of the molten steel relative to the horizontal line when the stream of the molten steel passes through the introduced area ;

A represents a width of a slab continuously cast; and

N represents a number of poles in the magnetic field generator.

4. The method of claim 1, characterized in that said first control step includes controlling a frequency of electric current to be frequency F of electric current or more, the frequency F being determined by an effective braking parameter E and an angle  $\alpha$ , the angle  $\alpha$  being formed by an axis of the exit port of the immersion nozzle in a direction of the poured molten steel relative to the horizontal line and ranging from  $60^\circ$  to  $25^\circ$  directed downwardly, and said effective braking parameter E being represented by the following formula :

$$E = (A \cdot B \cdot C) / \{ N \cdot (W - D) \cdot S \}$$

where

A represents a width[m] of the mold for the continuous casting of a slab ;

B represents a thickness[m] of the slab continuously cast ;

C represents a speed[m/sec.] of the continuous casting;

S represents an effective area[  $m^2$  ] of the exit port of the immersion nozzle ; and

N represents a number of poles in the magnetic field generator:

5. The method of claim 4, characterized in that said effective braking parameter E is represented with a straight line connecting (  $E = 0, F = 0$  ) and (  $E = 5, F = 1.5$  ) when the angle  $\alpha$  ranges from  $60^\circ$  to  $35^\circ$  both directed downwardly, the abscissa representing the effective braking parameter E and the ordinate representing the frequency F of electric current.

6. The method of claim 4, characterized in that said effective braking parameter E is represented with a straight line connecting (  $E = 0, F = 0$  ) and (  $E = 5, F = 1.4$  ) when the angle  $\alpha$  ranges from  $35^\circ$  to  $25^\circ$  directed downwardly, the abscissa representing the effective braking parameter E and the ordinate representing electric current frequency.

7. The method of claim 1, characterized in that said first control step includes controlling a frequency of electric current for generating the linearly shifting magnetic field to be frequency F of electric current or more, the frequency F being determined by an effective braking parameter E and an angle  $\alpha$ , the angle  $\alpha$  being formed by an axis of the exit port of the immersion nozzle in a direction of the poured molten steel relative to the horizontal line and ranging over  $25^\circ$  directed downwardly and below  $15^\circ$  inclusive, directed upwardly, and said effective braking parameter E being represented by the following formula :

$$E = 4 \cdot B \cdot C (\cos \alpha)^2 / \{ N \cdot A \cdot S \}$$

where

A represents a width[m] of the mold for the continuous casting of a slab ;

B represents a thickness[m] of the slab continuously cast ;

C represents a speed[ m/sec.] of the continuous casting;

S represents an effective area[  $m^2$  ] of the exit port of the immersion nozzle ; and

N represents a number of poles in the magnetic field generator:

8. The method of claim 7, characterized in that said effective braking parameter E is represented with a straight line connecting (  $E = 0, F = 0$  ) and (  $E = 5, F = 1.3$  ) when the angle  $\alpha$  ranges over  $25^\circ$  directed downwardly and below  $15^\circ$  inclusive, directed upwardly, the abscissa representing the effective braking parameter E and the ordinate representing the frequency F of electric current .

9. The method of claim 1, characterized in that said first control step includes controlling frequency of electric current for generating the linearly shifting magnetic field to be frequency f of electric current or more, the frequency f being calculated by multiplying frequency F of electric current by integer and the frequency F being determined by an effective braking parameter E and an angle  $\alpha$ , the angle  $\alpha$  being formed by an axis of the exit port of the immersion nozzle in a direction of the poured molten

steel relative to the horizontal line and ranging from 60 ° to 25 ° both directed downwardly, and said effective braking parameter E being represented by the following formula :

$$E = (A \cdot B \cdot C) / \{ N \cdot (W - D) \cdot S \}$$

where

A represents a width[m] of the mold for the continuous casting of a slab ;

B represents a thickness[m] of the slab continuously cast ;

C represents a speed[ m/sec.] of the continuous casting;

S represents an effective area[ m<sup>2</sup>] of the exit port of the immersion nozzle ; and

N represents a number of poles in the magnetic field generator:

10. The method of claim 9, characterized in that said effective braking parameter E is represented with a straight line connecting ( E = 0, F = 0 ) and ( E = 5, F = 1.5) when the angle  $\alpha$  ranges from 60 ° to 35 ° both directed upwardly, the abscissa representing the effective braking parameter E and the ordinate representing frequency F of electric current.

11. The method of claim 9, characterized in that said effective braking parameter E is represented with a straight line connecting ( E = 0, F = 0 ) and ( E = 5, F = 1.5), when the angle  $\alpha$  ranges over 35 ° directed downwardly and below 25 ° inclusive, directed upwardly the abscissa representing the effective braking parameter E and the ordinate representing the frequency F of electric current.

12. The method of claim 9, characterized in that said first control step includes controlling a frequency of electric current for generating the linearly shifting magnetic field to be frequency f of electric current or more, the frequency f being calculated by multiplying frequency F of electric current by integer and the frequency F being determined by an effective braking parameter E and an angle  $\alpha$ , the angle  $\alpha$  being formed by an axis of the exit port of the immersion nozzle in a direction of the poured molten steel relative to the horizontal line and ranging over 25 ° directed downwardly and below 15 ° directed upwardly, and said effective braking parameter E being represented by the following formula :

$$E = 2 \cdot B \cdot C (\cos \alpha)^2 / \{ N \cdot A \cdot S \}$$

where

A represents a width[m] of the mold for the continuous casting of a slab ;

B represents a thickness[m] of the slab continuously cast ;

C represents a speed[ m/sec.] of the continuous casting;

S represents an effective area[ m<sup>2</sup>] of the exit port of the immersion nozzle ; and

N represents a number of poles in the magnetic field generator:

13. The method of claim 12, characterized in that said effective braking parameter E is represented with a straight line connecting ( E = 0, F = 0 ) and ( E = 5, F = 3.5) when the angle  $\alpha$  ranges over 25 ° directed downwardly and below 15 ° inclusive, directed upwardly, the abscissa representing the effective braking parameter E and the ordinate representing the frequency F of electric current.

14. The method of claim 1, characterized in that said second control step includes controlling a frequency of electric current of the linearly shifting magnetic field so as for the density of the magnetic fluxes in the mold to have at least 1200 gauss.

15. The method of claim 14, characterized in that the frequency of electric current is 2.8 Hz.

FIG. 1

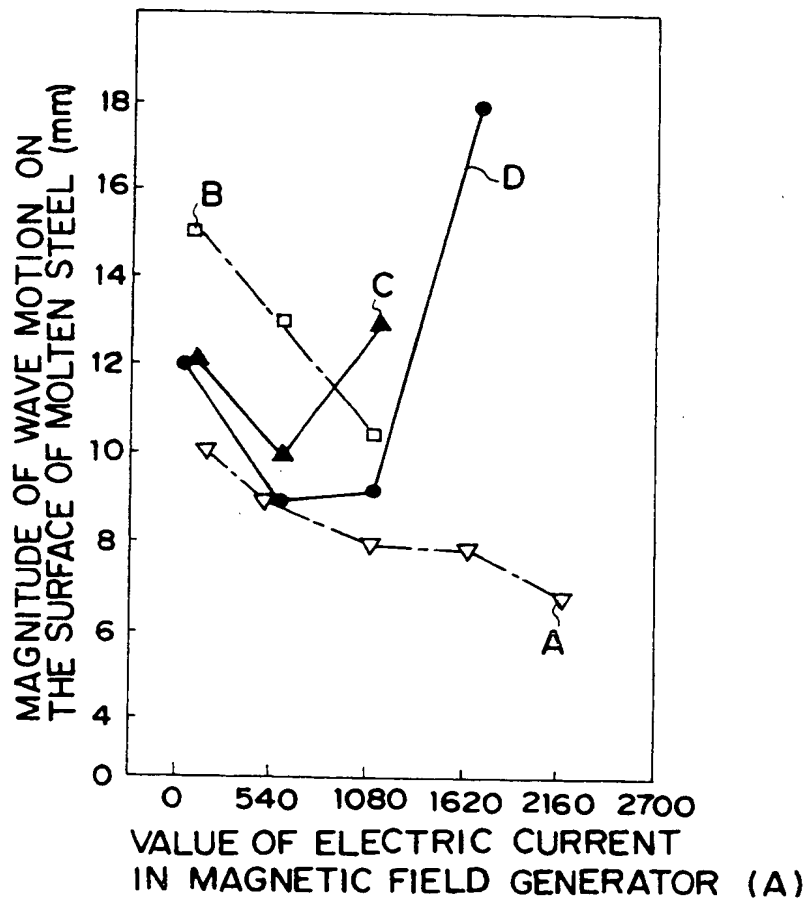


FIG. 2 (A)

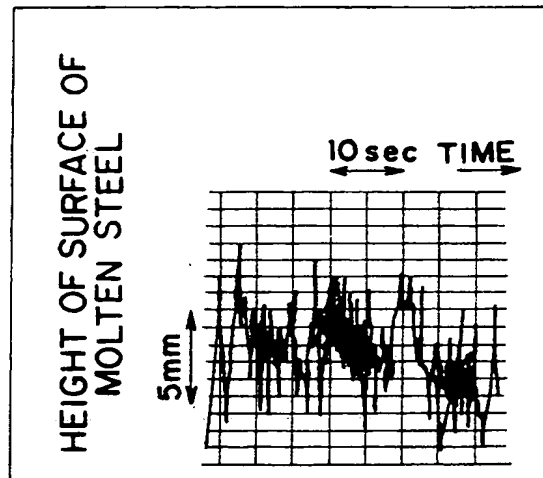


FIG. 2(B)

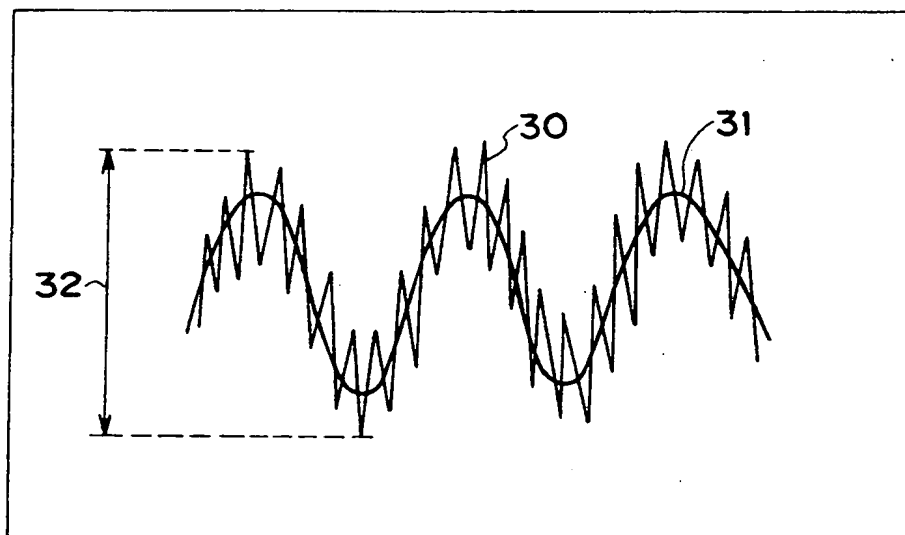
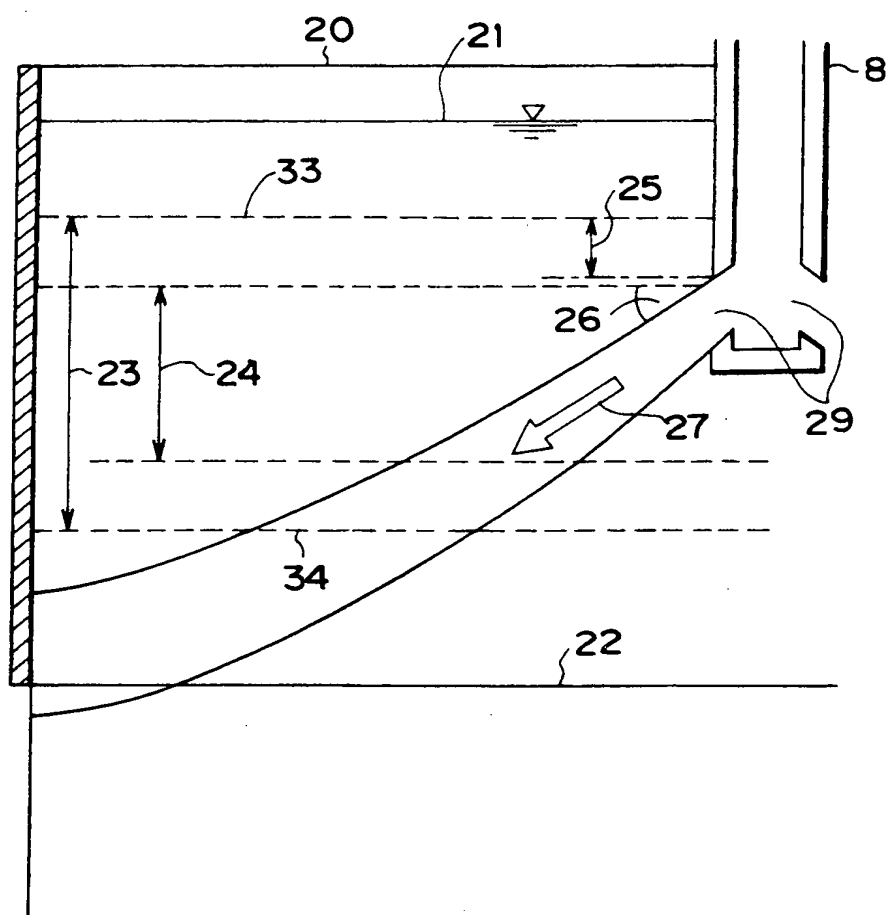




FIG. 3



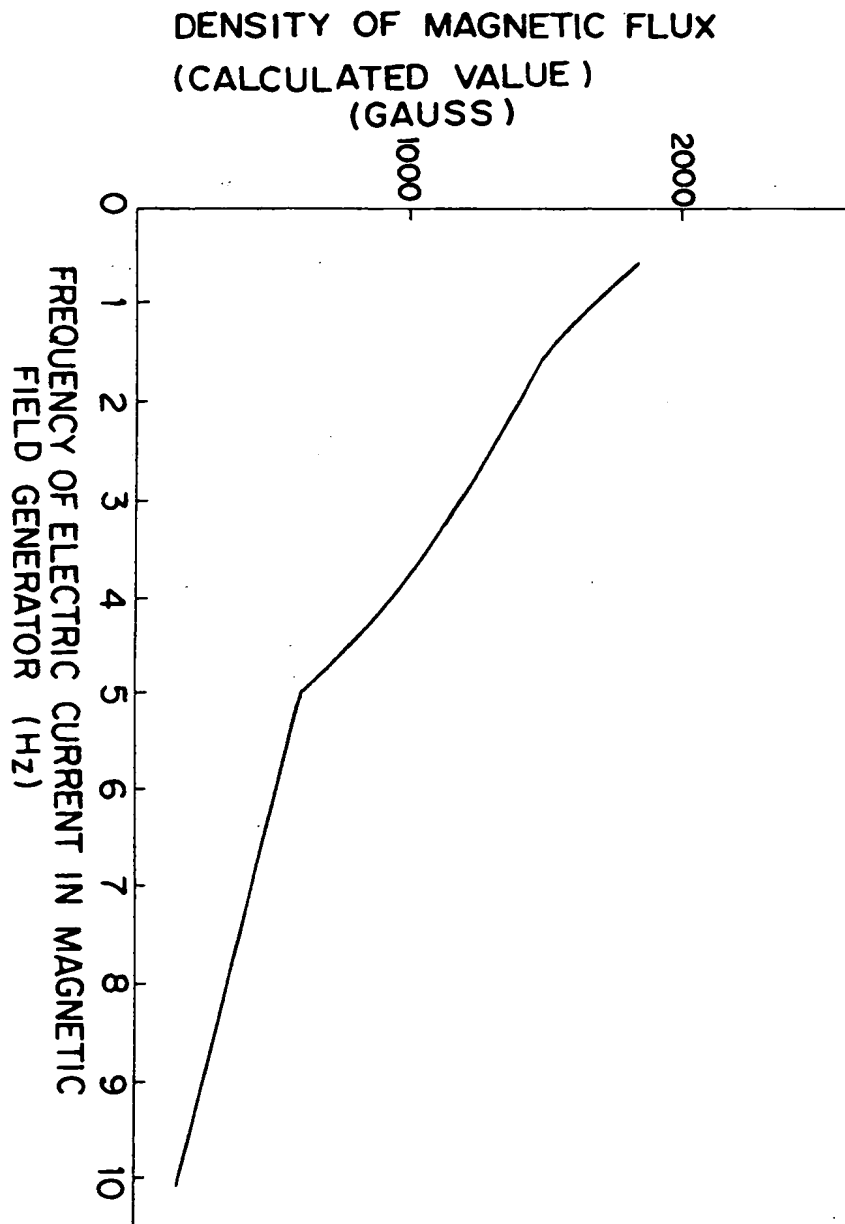


FIG. 4

FIG. 5

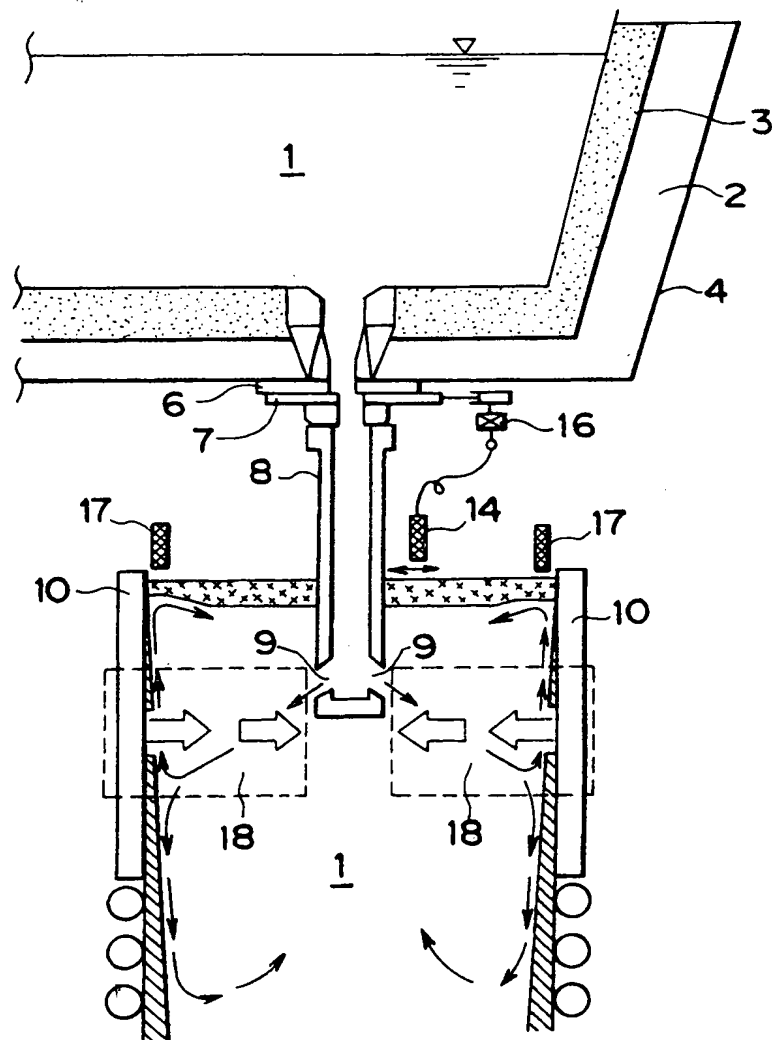


FIG. 6

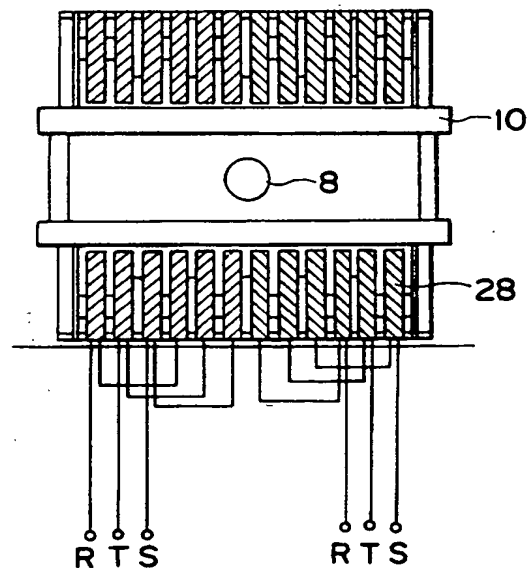


FIG. 7

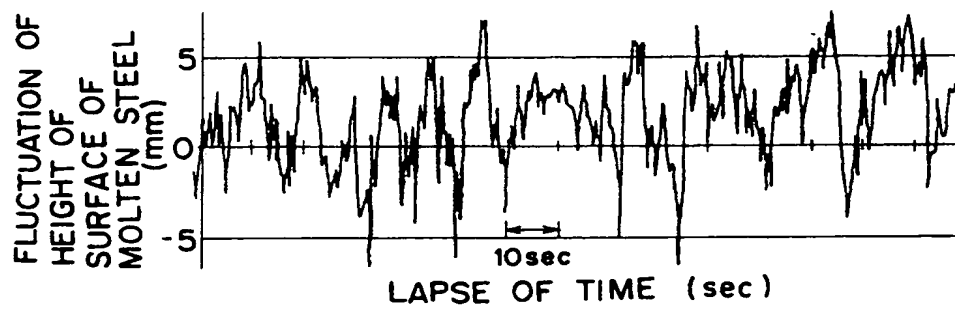


FIG. 8

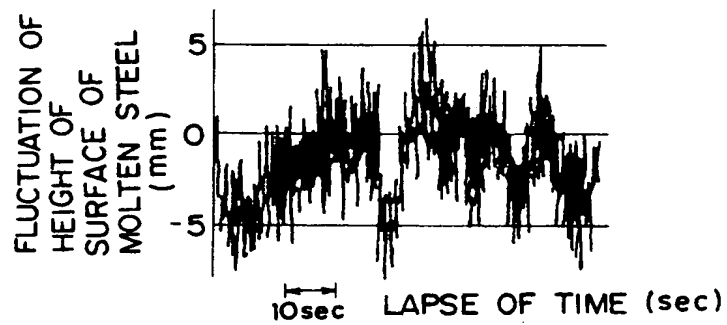


FIG. 9

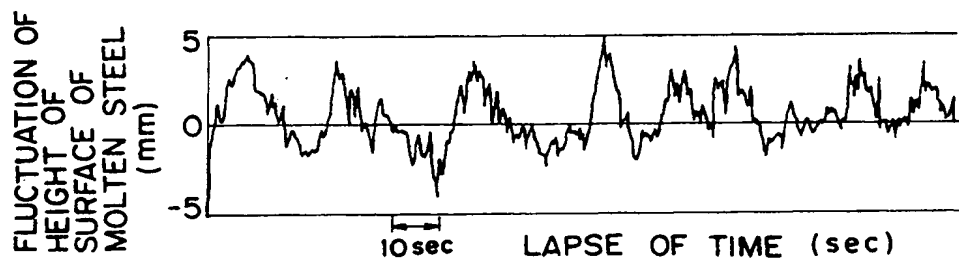


FIG. 10

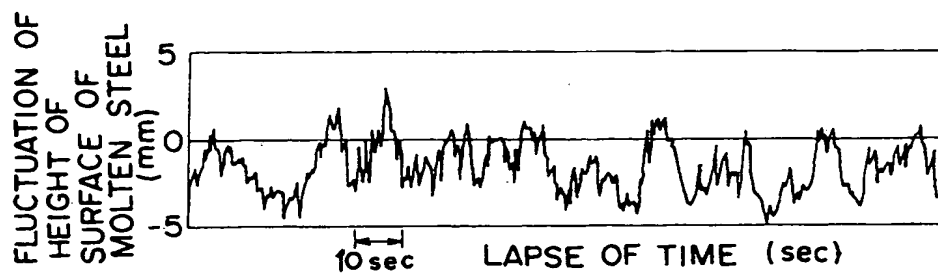


FIG. 11

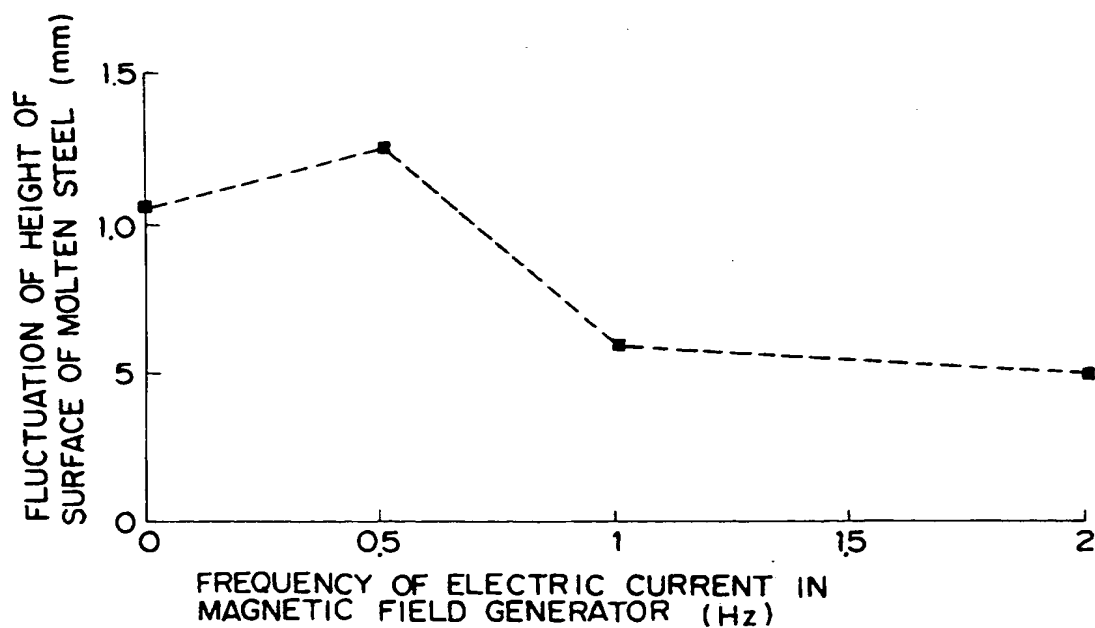


FIG. 12

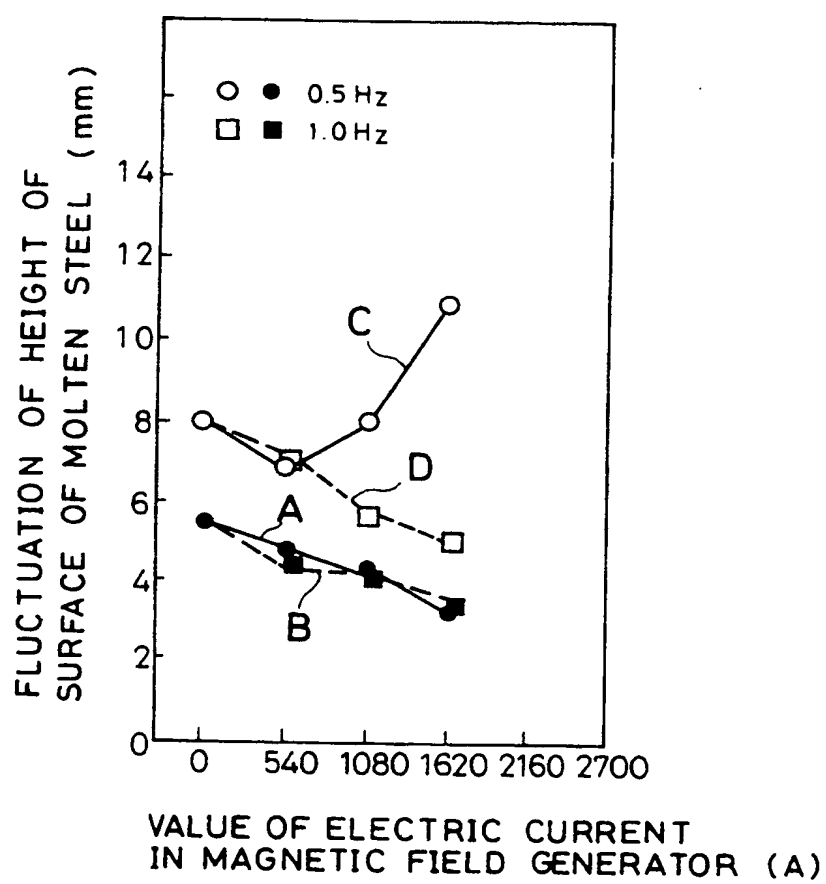


FIG.13

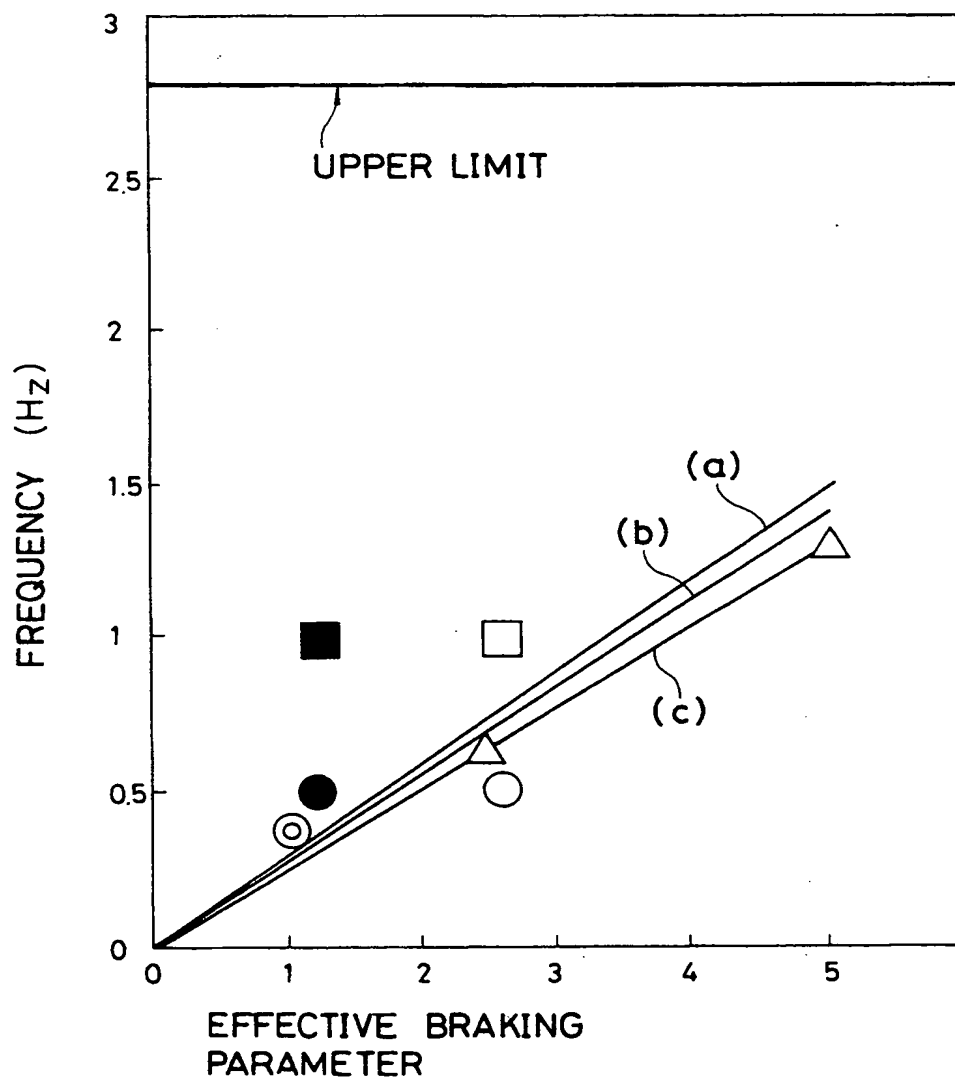
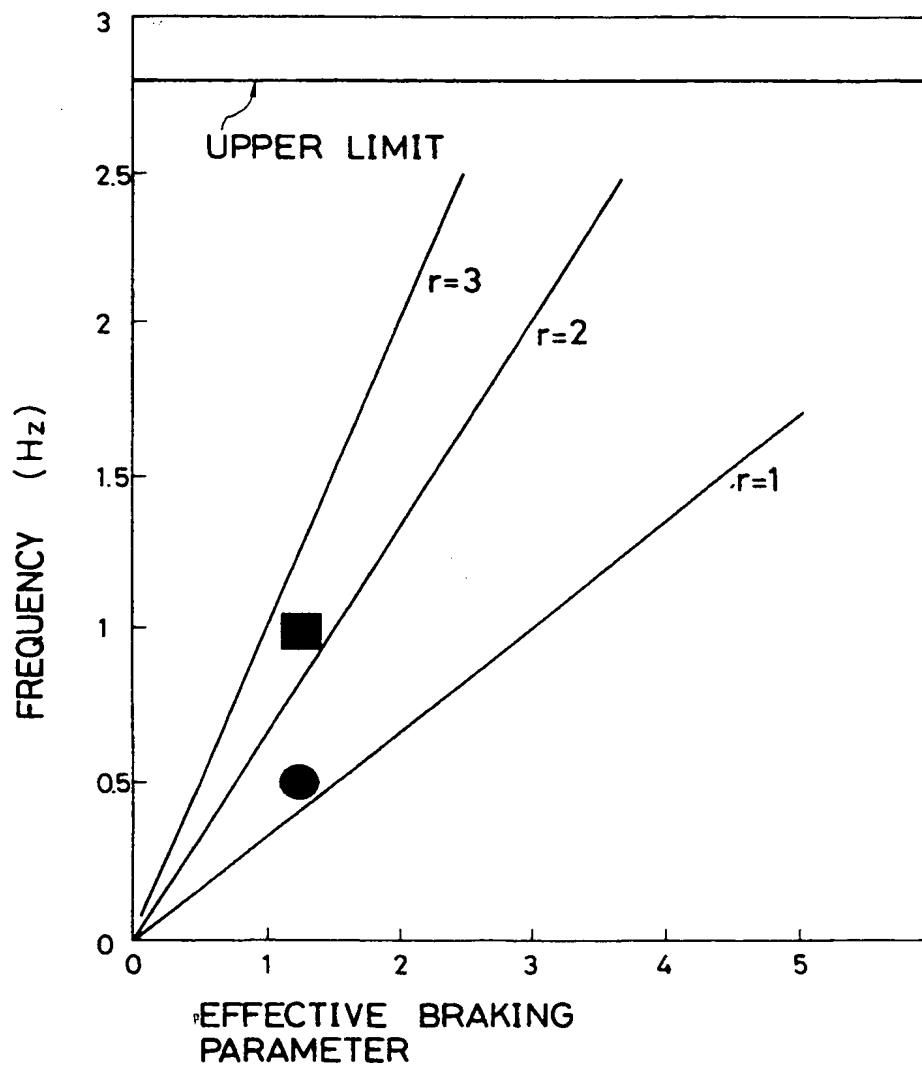




FIG.14





European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number

EP 92 10 0283

### DOCUMENTS CONSIDERED TO BE RELEVANT

| DOCUMENTS CONSIDERED TO BE RELEVANT |  |                   |   |
|-------------------------------------|--|-------------------|---|
| Category                            | Citation of document with indication, where appropriate, of relevant passages  | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl.5) |
| X                                   | EP-A-0 040 383 (ASEA AB)<br>* claims; figures *<br>----  | 1                 | B22D11/10<br>B22D11/12<br>B22D11/18           |
| X                                   | PATENT ABSTRACTS OF JAPAN<br>vol. 13, no. 265 (M-839)(3613) 19 June 1989<br>& JP-A-1 066 055 ( NKK CORP ) 13 March 1989<br>* abstract *<br>----  | 1                 |   |
| X                                   | PATENT ABSTRACTS OF JAPAN<br>vol. 6, no. 45 (M-118)(923) 20 May 1982<br>& JP-A-56 160 862 ( KAWASAKI SEITESTU K.K. ) 10 December 1981<br>* abstract *<br>----  | 1                 |   |
| X                                   | EP-A-0 401 504 (KAWASAKI STEEL CORP)<br>* the whole document *<br>----   | 1                 |   |
| A                                   | EP-A-0 405 948 (KABUSHIKI KAISHA KOBE 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